FAILURE IS NOT AN F-WORD: IF YOU'RE NOT FAILING, YOU'RE NOT LEARNING

Caro Williams-Pierce
University of Maryland
carowp@umd.edu

I often use the word 'failure' in my work, and the audience I'm talking to dictates their response to my use of that word. I remember back in grad school, saying the word 'failure' in a mathematics education class, and everyone gasped in horror at the f-word! But just down the hall, where I studied games and learning with other folks, we talked about our experiences of failure in games all the time – no gasping required. Because good games always have useful feedback paired directly with any moment of dramatic failure – that is not always (maybe even *not often*) true in classrooms (or indeed, academia in general).

My provocation is: we need to normalize joyful failure at every step in the mathematics learning process. And to do that, we need to make sure that our feedback is consistent and useful – and provokes reflection on the mathematics and our learning, instead of frustration or rote memorization. There are many ways to design such failure and feedback experiences, and I present one such approach here.

Provocative Objects

In examining failure and learning, I've pretty much become obsessed with mathematical play in all sorts of different contexts. In particular, I think of mathematical play as being particularly likely to emerge when failure paired with feedback are regularly present for the player/learner. I developed the idea of a *provocative object* as a particular tool to designing to support mathematical play and learning (e.g., Williams-Pierce, 2019; Williams-Pierce & Thevenow-Harrison, 2021). Initially, provocative objects emerged as a way of thinking about and designing for mathematical play in videogames; however, we recently extended this construct to *provocative environments* in order to better examine and understand mathematical play in informal makerspaces (Shokeen et al., 2020). Consequently, while I focus primarily on provocative *objects* below, I also describe some of the more recent insights we have developed.

Provocative objects are digital environments that provoke mathematical play and learning by using five key characteristics that can be used for both design and analysis purposes.

#1: Consistent and Useful Feedback

First, provocative objects have consistent and useful feedback. Often, we engage with mathematics in environments that do not provide immediate feedback. For example, if I hand you an expression on a piece of paper (Figure 1), you can simplify it any number of ways, both correct and incorrect.

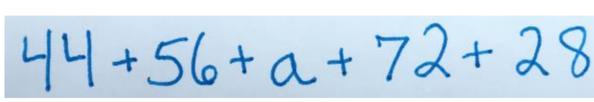

Figure 1: an expression written on paper.

If you decide that you can add 56 and *a* together and you write down 56*a*, the paper will not revolt. You can write it down, hand it in, and wander off to recess – and if you're lucky, you'll get feedback on your failure the following day or week. But with a digital context, like Ottmar

Olanoff, D., Johnson, K., & Spitzer, S. (2021). *Proceedings of the forty-third annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Philadelphia, PA.

and team's *From Here to There* (FH2T; Figure 2), you get feedback about that impossibility immediately.

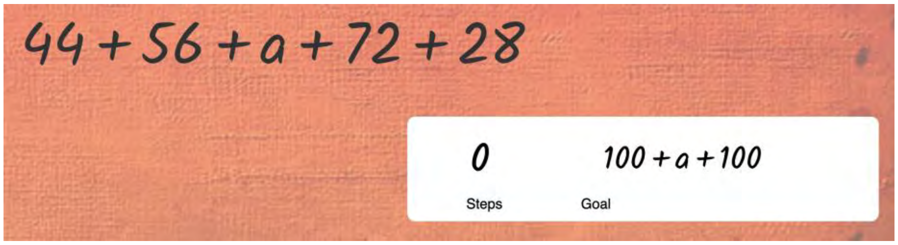

Figure 2: World 1, Puzzle 6. In FH2T, the goal is to modify the top expression to duplicate the target expression in white.

If you tap the + symbol between the 44 and 56, the game will enact the addition, giving you a total of 100 – and feedback that you are engaging in a mathematically possible action. But if you tap the + symbol between the 56 and *a*, the + will shake back and forth – feedback that indicates a mathematically impossible action. In other words, unlike paper, FH2T gives immediate and useful feedback to learners.

#2: Failure Paired with Feedback

The full name of this second characteristic is *high enough levels of difficulty and ambiguity that players experience frequent failure that is closely paired with the feedback.* Failure is so important that when I was designing my dissertation game, *Rolly's Adventure* (RA), one of my first design decisions was how to indicate failure, and how to closely pair that failure directly to feedback without just *telling* the player what they did wrong. That is, how do you tell someone playfully that they are failing, and pair it with feedback that – instead of telling them the answer - helps them reflect upon what they did, so they can learn from it?

This often contrasts with traditional learning contexts – where failure *is* an F-word - and I rely upon game scholars who study failure to understand how wonderful failure can be (e.g., Juul, 2009; Ramirez, 2017). In particular, because the feedback is consistent and useful, every instance of failure comes immediately in the moment: players can see the results of their actions, reflect upon the relationship between their action and the failure/feedback their action evoked, and learn (Williams-Pierce, Dogan, & Ellis, 2021, in revision). For example, in RA, one player was surprised and excited when he experienced failure for the first time (Figure 3).

Figure 3: Emmett (left) experiences fiery death as an indicator of failure in RA (right).

Immediately after this moment of fiery failure, a huge slow grin spread across Emmett's face: "Wh- wh- what?! What the— heck? I don't even know—what just happened?"

So, the first point is that he did not mind failing – shocked surprise was followed immediately by curiosity and interest. And that curiosity and interest led Emmett to discover the feedback that he had not noticed during this first failure: he had not achieved the puzzle goal of perfectly filling the hole (Figure 4).

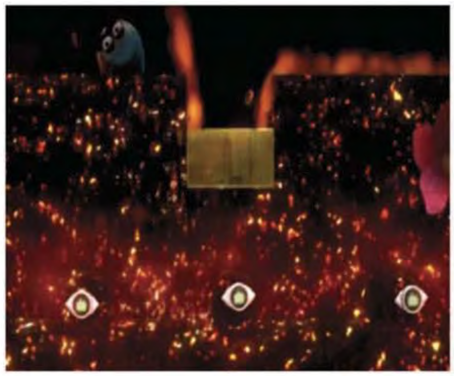

Figure 4: Visual feedback in RA, paired with the fiery failure. (A different puzzle than the previous Figure, as this puzzle is lighter and easier to see in screenshots.)

Note that the fiery death of his adorable avatar (see the rainbow faced minion in Figure 3, right) was the failure indicator, and the feedback indicator (the golden block in Figure 4 that only partially fills the whole) is *not* on fire. The eye of the player is drawn to that golden block, as one of the very few objects not on fire, which helps emphasize the feedback indicator in an otherwise novel (and thus bewildering) context.

However, failure and feedback can be more complex, especially in provocative environments. For example, in ongoing research with Amber Simpson in our mmPlay lab, we've been identifying indicators of failure and feedback in collaborative non-formal robotics makerspaces in elementary school. In this context, failure and feedback are often social in nature, as the students negotiate together to achieve their common goal (Shokeen et al., this volume), rather than a reaction from a designed object.

#3: Non-Standard Mathematical Representations and Interactions

Somehow, our field often seems to settle for ossified representations of and interactions with mathematics for our learners. We point at an expression like $56 + a$, and are deeply confused by our learners trying to add two unlike terms. Much like Emmett not yet seeing the feedback paired with the failure indicator, our learners don't look at a and think that it could be 17, or the color blue, or 80 degrees Fahrenheit – in other words, a does not yet represent *unlike-ness* to them. These learners may instead memorize the rule against adding unlike terms, and try to apply it whenever it seems appropriate. As a consequence, when learners encounter standard representations or interactions, they may immediately try to unthinkingly use a plethora of inappropriate memorized rules. This third characteristic is about avoiding evoking such rules (or a player's mathophobia!), in order to better support learners in joyfully engaging in the mathematics that undergirds both standard and non-standard representations and interactions.

However, this leads to another issue: mathematics learning contexts often over-rely upon written and spoken language as feedback and evidence of learning, instead of letting the

mathematics speak directly to the player as happens in RA, or letting the learner use complex modalities to share their understanding (such as gesture; e.g., Williams-Pierce et al., 2017; see also Ng, 2016, for an excellent example of learners using gesture to supplement their mathematics communication in their non-primary langauge). As a result, we struggle as a field to *see* mathematics learning in action because we rely upon written or spoken versions of our ossified school-based field. In our mmPlay lab research, we have found that there are multiple layers of mathematical activity occurring that do not directly manifest in written or spoken language, or manifest as a trivial change in such forms. For the former, as mentioned above, there are gestures that act to uniquely complement spoken language. For the latter, for example, when programming the robot Dash to traverse a path, a student may program in a distance in specific units, only to see Dash go too far. The student then must perceptually compare Dash's location with the desired distance, estimate how much *too far* is, and revise their input to test out their new hypothesis. Here, there is failure (Dash did not stop where the student wanted it to), feedback (the student can visually perceive that Dash went too far), and mathematical activity that involves mentally simulating the distance between the lengths (Williams-Pierce et al., this volume). This mathematical activity may manifest simply in a student revising the code in the application that controls Dash, but that small change represents considerable (and easily missed) mathematical activity on the part of the student.

#4: Mathematical Notation Introduced Late or Not at All

This fourth characteristic is one of my favorites, but it also may be very wrong! Essentially, a provocative object does not start with notation, and only introduces it when – or if – it becomes a deeply useful tool to the learner in their gameplay. Earlier, I used FH2T as an example of the first characteristic because I believe it is a provocative object, but FH2T very clearly violates *this* characteristic as formal notation is the primary representation type in FH2T! Consequently, I'm really psyched that one of my doctoral students, Nihal Katirci, is examining FH2T, mathematical play, and learning for her dissertation. So she'll be the one to tell me if this characteristic is less important than I originally believed, and that I need to dial it down to allow for games like FH2T. But I want to emphasize this crucial fact: I am not *anti-notation*, but I am anti-*notation being mistaken as the math itself*. We have the unfortunate habit of taking representations and teaching learners that those representations *are* the mathematics, instead of merely another *representation* of the mathematics. Stay tuned for Nihal's findings!

#5: The Legitimate Possibility of Alternative Conceptual Paths

Last but certainly not least! RA is a linear puzzle game: you complete one puzzle, then you get to go to the next, and so on – you cannot go from puzzle 1 to puzzle 7 and back to puzzle 2. From one perspective, this can be seen as a violation of this fifth characteristic, but as long as your provocative object is ambiguous and challenging (and rife with failure and feedback), a linear product does *not* dictate a linear conceptual path. In the case of RA, players develop their own conceptual understanding of the mathematics underlying the game, using the non-standard representations and interactions in order to craft their own unique mathematical narrative, and emerge from their gameplay with different experiences. I suspect that FH2T is the same – as I said above, stay tuned for more about that!

Conclusion

In summary, I believe that in mathematics education, with ourselves AND with our students or learners, we need to embrace failure as a beautiful thing – an incredibly wonderful opportunity to learn more about the math or the tool or the people. The five characteristics of provocative

objects can help us understand how to *design* such lovely failure, as well as how to *understand* the amazing failure that happens within tools or in our lives.

Acknowledgments

Many thanks to Erin Ottmar for permission to use screenshots of *From Here to There*. The mmPlay lab consists of the author, Amber Simpson, Nihal Katirci, Ekta Shokeen, and Janet Bih, all of whom contributed to the ideas within this paper. The player name of Emmett is a pseudonym. Lastly, this manuscript serves as a *complement* to the plenary provocation presented at the conference, not a duplicate!

References

Juul, J. (2009). Fear of failing? The many meanings of difficulty in video games. *The Video Game Theory Reader, 2*, 237–252. https://doi.org/10.1017/ 550 CBO9781107415324.004

Ng, O. L. (2016). The interplay between language, gestures, dragging and diagrams in bilingual learners' mathematical communications. *Educational Studies in Mathematics*, *91*(3), 307–326. https://doi.org/10.1007/s10649-015-9652-9

Ramirez, D. (2017). Failure by Design: Encouraging learning through failure with games. *Game Developer.* Retrieved from https://www.gamedeveloper.com/design/failure-by-design-encouraging-learning-through-failure-with-games-

Shokeen, E., Katirci, N., Bih J., Simpson, A., & Williams-Pierce, C. (2020). *Unpacking mathematical play within makerspaces using embodied cognition.* Extended Abstract in the 2020 Annual Symposium on Computer-Human Interaction in Play (CHIPLAY). Ottawa, Canada.

Shokeen, E., Simpson, A., Katirci, N., & Williams-Pierce, C. (accepted). *Use of zig-zag to represent mathematical thinking about angle.* Accepted to the North American Chapter of the International Group for the Psychology of Mathematics Education.

Williams-Pierce, C., Dogan, M.F., & Ellis, A.B. (2021). *Multimodal generalizing in a mathematical videogame.* In E. de Vries, E., Y. Hod, & J. Ahn (Eds.), Proceedings of the 15th International Conference of the Learning Sciences (pp. 641-644). Bochum, Germany: International Society of the Learning Sciences.

Williams-Pierce, C., Katirci, N., Simpson, A., Shokeen, E., & Bih, J. (accepted). *Revealing mathematical activity in non-formal learning spaces.* Accepted to the North American Chapter of the International Group for the Psychology of Mathematics Education.

Williams-Pierce, C., Pier, E., Walkington, C., Clinton, V., Boncoddo, R. Nathan, M., & Alibali, M. (2017). What we say and how we do: Action, gesture, and language in proving. *Journal for Research in Mathematics Education*, *48*(3), 248-260.